DETAILS OF THE INITIAL PART OF THE TUNGSTEN ION LINAC FOR PARTICLE TRACK MEMBRANES PRODUCTION

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Abstract

The data of designing, tuning and tests on the initial part of the heavy ion linac main systems, that are the 35 kV ion beam injector with the MEVVA-type ion source, the 5 MeV 3m long acceleration section with RFQ and the 0.4 MeV/amu 6m long pre-stripper section with the alternating phase focusing (APF), are presented. The injector produces intensive tungsten ion beam with the working charge of +4, the beam pulse length of 300 mcs and the repetition rate of 25 pps. The main construction feature of the sectionalized RFQ structure are the ceramic insulators as mechanic supports for the 4-rod modulated line. The high power tests data for the single cell of the RFQ structure are given. The APF prestripper section design is described.

I. INTRODUCTION

The RF linac-based technological complex for particle track membranes (PTM) industrial production is under developing now in Russia [1]. The dedicated heavy ion linac is developing in the anticipation of high demand for extra quality membrane products, especially for sterilizing ones. The productivity of the accelerator complex is expected to be not less than some hundred thousands m^2 of irradiated polymer film per year.

First, it must reach high production rate and capacity combined with high quality of irradiation (porosity $\geq 20\%$, irradiation nonuniformity $\leq \pm 5\%$, wide range of film thickness, i.e 10-30 μm). Secondly, the installation must be energetically effective. At last, the industrial linac must be extremely compact, reliable and convinient for maintainances by non-specialized enterprise personnel.

The schematic layout of the 1.7 MeV/amu heavy ion linac for industrial PTM production is shown in Fig.1.

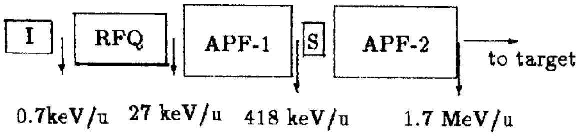

Figure. 1. The schematic layout of the linac

The heavy ion linac consists of five basic units:

- injection unit, which consists of the 35 kV injector based on metal evaporation vacuum arc ion source and beam formation and preminary acceleration section including electrostatic matching channel and RFQ accelerator section
- prestripper APF section,
- intermediate stripper section,
- poststripper APF section,
- exit beam formation line.

Pulse beams of tungsten ions with the designed charge of +4, being produced in the MEVVA type ion source, pass than through high voltage injector terminal of 35 kV and static matching channel. The RF matching of the beam, its bunching and preliminary acceleration is carried out in the 3m long RFQ. The main acceleration is executed in two alternating phase focusing (APF) sections, both 6 m long, up to the final energy of 1.7 MeV/amu. The intermediate beam recharge up to the equilibrium charge of +16 is provided in between two APF sections by a gas stripper at the energy of 0.42 MeV/amu. As the RFQ section so the APF prestripper section are supplied with pulse RF power at the industrially permitted frequency of 40.7 MHz (under maximum pulse length of 800 μs and repetition rate of 25 pps), though the stripped beam is accelerated at doubled frequency of 81.4 MHz. Exit beam sweep and formation at the irradiation target is provided by system of multipole lenses for acceptable pulse irradiation of a wide constantly moving roll of a polymer film. Maximum permissible number of parasitic pores comply with the case when the film porosity per one pulse does not exceed 0.8%. So the getting of optimum porosity of 20% corresponds to a pulse irradiation under variable angles of the incident ions with the repetition rate of 25 pps in accordance with restrictions on percentage of parasitic (doubled and more) pores.

II. INJECTOR

The injector for an industrial complex must maintain stable and reliable pulse supply for the linac structure with heavy ions. Comparatively low injection potential of $\leq$ 35 kV have been chosen for the exploitation convenience. The layout of the source design is shown in Figure 2.

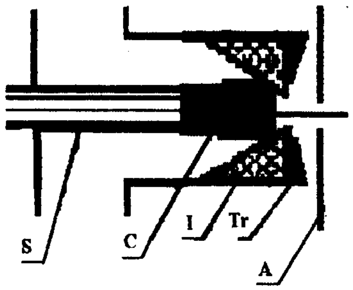

Figure. 2. The schematic design of the ion source

The elegant construction of the MEVVA-type ion source [2] has been developed for the operation with the pulse length of 400 μs and the repetition rate of 25 pps. It can provide at least some tens mA of total beam current taking into account the percentage of the designed W^{4+} component does not exceed one-third of total beam intensity. The cathode block construction gives a possibility of quick renewal of the used cathode by enterprise operating personnel.

Plasma being created by vacuum ark discharge penetrates then through the hole in the anode and the metal ion beam is extracted from its surface and formed by adding accel-decel system. The main problems for industrial applications of this type of ion source are stability, reproducibility and lifetime.

Mechanically the cathode (C) is a small tungsten cylinder of 30 mm long and 4 mm in diameter which is fixed at the copper mounting slug welded on a bellow. The slug sizes must also be extremely small to facilitate effective cathode cooling.

The bellow is used as a spring for the cylindric cathode clamping tightly to the inner surface of the aluminum-oxide insulator (I) with a cone hole. It gives a posibility to convey the cooling water as close as possible to the cathode surface. A spring support facilitates both reliable contact between cathode and insulator surfaces and stabilization of the cathode front surface placement during its burning-out. The described assembly is clamped to the stainless steel triggering electrode (Tr) whose construction permits to change the distance between the triggering electrode and cathode along the insulator surface for the searching of the optimum position. This position reduces to a trade-off of reliability of discharge initiation at small distances against the requirement to avoid insulator surface metallization at large distances. The cathode, the triggering electrod and the insulator are joined in the common cathode unit which provides fairly stable triggering and discharge regimes. Insulator metal spraying process is the one of main restricts for the source lifetime. The metal film is evaporated only during triggering discharges. In [3] was shown in assuming of the equality of trigger and main discharges duration that triggering and main discharge currents must satisfy the following relationship:

$$I_{tr}/I_d \geq k \cdot (\sqrt{\Delta t}/a), \tag{1}$$

where I_{tr},I_d are triggerring and discharge currents correspondently, k - the factor depending on physical properties of the cathode material, Δt - the pulse duration of ark discharge, and a - the distance between C and TE along the insulator surface. In our case of a=3mm and I_d = 80 A, the $\frac{I_{tr}}{I_d} \geq 0.25$ (the arc current amplitude is defined from the requirement of the arc continuity during the required time). The source anode (A) mechanically is a copper ring with an axial hole of 10 mm in diameter. The anode-cathode distance of 6 mm was chosen.

The operating amplitude and duration of triggering pulse are 8 kV and 15 μsec correspondently. The igniting discharge is driven by the modulator with inductor current stabilizer (MAC). This modulator provides more stable arc and beam characteristics in comparison with LC pulse line modulator. MAC provides discharge current amplitudes up to 200 A. The discharge duration may be varied from 15 μsec (the triggering pulse duration) up to 900 μsec. The operating regime is maintained at the discharge arc current value of 80 A at pulse duration of 400 μsec.

Recent tests on improving of the operational stability under designed values of pulse length and repetition rate maintain stable regimes of the arc generator during several hours of nonstop work.

III. RFQ SECTION

The designed beam parameters of the RFQ section are listed in the table 1:

Table I

RFQ Section Design Parameters

Charge-to-mass ratio	1/46
Initial energy, keV/amu	0.7
Final energy, keV/amu	27
Resonant frequency, MHz	40.7
Aperture diameter,mm	4.6
Maximum field strength,kV/cm	173.7
Normalized acceptance, $\pi mm \cdot mrad$	2.5
Exit velosity spread, %	1.2
Exit phase spread, deg	20
Beam current limit, mA	6.1

The RFQ resonator construction includes four-rod modular line with stainless steel pole pieces and copper support bars fixed on the resonator jacket by means of ceramic insulators due to comparatevely small operating RF voltages on rods.

The use of RF insulators decreases transversal sizes of the structure markedly with no dramatic changes in the RF structure parameters. These insolators are placed on adjustment stages fixed at the resonator frame. Copper resonant spirals are tapped down between support bars and a frame to get designed frequency of 40.7 MHz. Electric coupling half-rings provide low impedance connection between the diametrally opposed rods for decreasing of sensitivity to misalignments and RF working mode stabilization. The cooling of the structure is furnished by distilled water which is running inside resonant spirals and cooling tubes fixed in support bars. Longitudinally the RFQ section construction includes four cells, 700 mm long each, joined with each other.

The structure is arranged inside a common electric shell of 700 mm in diameter and 3 m long.

During the RF cold tests with a single cell full-scale model the transversal and longitudinal electric fields between adjacent were tuned not worse than ± 2.5% and 1.1% correspondently.

Independent vacuum tests with a single cell of the RFQ structure (fig.3) have demonstrated acceptable electric strength of the ceramic insulators. During one week tests under repetition rate of 25 pps and pulse length up to $400\mu s$ fairly stable RF regimes were reached.

IV. PRESTRIPPER APF SECTION

The prestripper section is intended for the pulse acceleration of 2 mA tungsten ion beam with charge +4 to the exit energy of 418 keV/amu. It is also designed for the working at the industrially permitted frequency of 40.67 MHz.

The designed values of phase capture are 50^o and 1.0%. A rather small momentum spread allows to consider the APF channel as a narrow bandwidth filter that prevents beam parasitic components moving to the exit. It will probably improve the uniformity of polymer film irradiation at a target. On the other hand, comparatively small beam intensities per one pulse are desirable

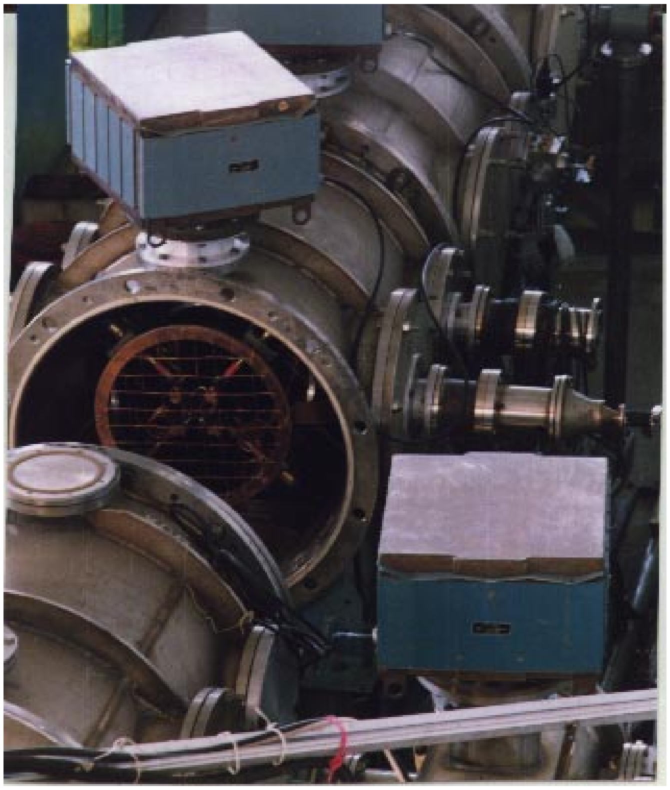

Figure. 3. The RFQ section test installation

Table II

APF Prestripper Section Design Parameters

Charge-to-mass ratio	1/46
Initial energy, keV/amu	27
Final energy, keV/amu	418
Resonant frequency, MHz	40.7
Aperture diameter,mm	7
Maximum field strength,kV/cm	100
Section length, m	6
Beam current limit, mA	2

to prevent the ”multihole” statistic problem, although acceptable productivity is reached by repeated many times (25 pps) film irradiations at different angles.

The layout of the full-scale model of the 6m long prestripper APF section is shown in fig.4. The twin line Wideroe-type APF accelerating structure is placed inside the 6m long and 1.2m in diameter stainless steel vacuum tank. Both longitudinal resonant electrodes made of square hollow bars are arranged in horizontal plane symmetrically with respect to the accelerator axis and supported by vertical hollow (again for cooling) copper resonant rods. The drift tubes free of any focusing lenses are arranged and bolted by turns on both longitudinal bars. An output copper jacket of the resonator is fixed mechanically inside the 6-side stainless steel framework which furnished with wheels to move the structure into the vacuum tank.

The maximum value of the field gradient in accelerating gaps does not exceed 100 kV/cm for exploitation reliability. The section contains 84 drift tubes with outer diameters from 35 mm to 70 mm and the aperture diameter of 10 mm. The cold RF tests made on the full-scale model showed principal possibility of tuning the structure on required frequency and electric field distribution.

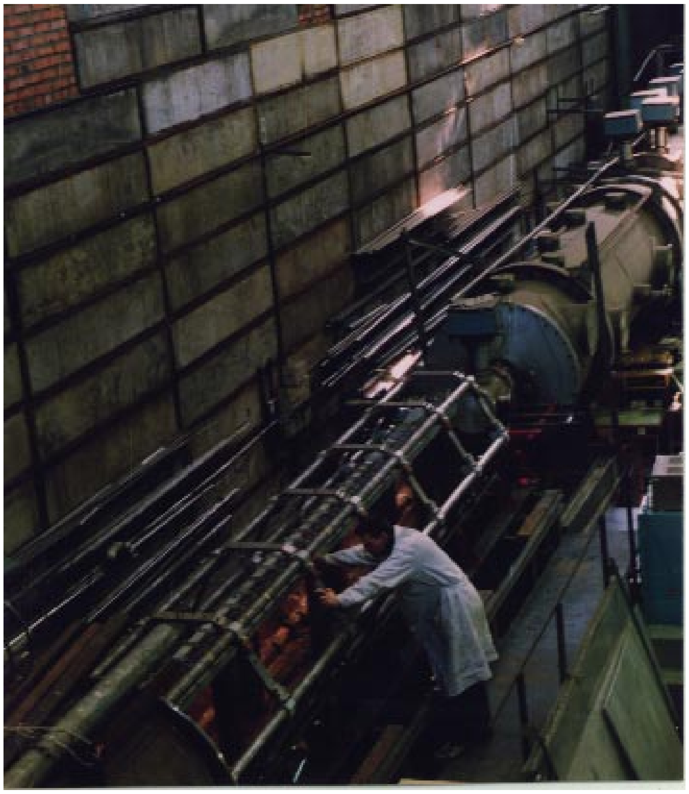

Figure. 4. Full-scale model of the APF prestripper section

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